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Energy and cost analyses of biodiesel production from waste cooking oil

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A B S T R A C T

Waste cooking oil is one of the energy sources for its unique composition which contains glycerol, It can be a good base for producing biodiesel. The objective of this study is to perform the energy and economic analyses of biodiesel production from Waste Cooking Oil (WCO) by the conventional transesterification method at the Tarbiat Modares University, Tehran, Iran. Data is acceded by performed biodiesel machine, with three replications during spring season (2012) in the same condition. The volume of biodiesel machine is 2000 L and the area of this lab is 100 m^2. The total energy input and energy output were calculated as 30.05 and 44.91 MJ L^{-1}, respectively. The energy output/input ratio was 1.49 in biodiesel production. The shares of renewable and non-renewable energy were 77.31% and 22.69%, respectively from total energy input. The benefit to cost ratio was found to be 2.081 according to the result of economical analysis of biodiesel production. The mean net return and productivity from biodiesel production were found to be 1.298 \$ L^{-1} and 0.946 kg \$$^{-1}$, respectively. The results showed that by applying ultrasonic and microwave instead of transesterfication and great managing, more benefit can be resulted.

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1. Introduction

Biomass can be re-grown from seeds or plant parts as long as solar energy, soil nutrients and a source of water exist. For this reason, biomass is recognized as a renewable source of energy. In recent years global interest in renewable energy production has significantly increased due to being eco-friendly and is seen as a means of helping to reduce global warming by displacing the use of fossil fuels. However, to be considered as a sustainable source, the input of energy required for biomass production must not exceed the output or amount of energy that can be extracted from the biomass. Due to its renewable, biodegradable, nontoxic and environmentally beneficial characteristics, biofuel is considered as an ideal alternative for fossil fuels. The production and use of biofuel has the potential of reducing dependence on petroleum, improving environmental quality, lowering the amount of emissions produced by human activities such as greenhouse gases (GHG), promoting rural development, and providing job opportunities [1,2]. Like many other countries such as the United States of America and some European Union countries [3], China is laying much effort in producing biofuel for vehicles and easing the great pressures from oil scarcity and environmental degradation, and at the same time promoting rural development. In 2006, the National Development and

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Reform Commission of China set a target of meeting 15% of transportation energy needs with biofuel by 2020 [4].

The production of first generation biofuels whose feedstock is agricultural crops will have a negative effect on food security if it is produced in large quantities [5,6]. However, using biomass crop produced from non-agricultural land as feedstock to produce second generation biofuels will not affect food security, and can be more conducive to improve the environment than the first generation biofuels. That is, sustainable biofuel production will be better achieved with a shift from the production of first generation biofuel to that of second generation biofuel [1,7].

Biodiesel is a mono-alkyl ester of long chain fatty acids produced from renewable feedstock. Biodiesel, having a chemical structure of fatty acid alkyl esters (usually fatty acid methyl ester, FAME), has recently become an alternative for petroleum-based diesel fuel. It is a non-toxic, biodegradable, relatively less inflammable fuel compared to the normal diesel and has significantly lower emissions than petroleum-based diesel [8]. In addition, biodiesel is better than diesel fuel in terms of sulfur content, flash point, aromatic content and cetane number [9]. Edible vegetable oils such as canola, soybean, and corn have been used for biodiesel production and found to be a diesel substitute [10,11]. However, a major obstacle in the commercialization of biodiesel production from edible vegetable oil is its high production cost, which is due to the high cost of edible oil. Waste cooking oil, which is much less expensive than edible vegetable oil, is a promising alternative for edible vegetable oil [12]. Waste cooking oil and fats set forth significant disposal problems in many parts of the world. This environmental problem could be solved by proper utilization and management of waste cooking oil as a fuel. Many developed countries have set policies that penalize the disposal of waste cooking oil the waste drainage [13]. The Energy Information Administration in the United States estimated that around 100 million gallons of waste cooking oil are produced per day in USA, where the average per capita waste cooking oil was reported to be 9 pounds [14]. The estimated amount of waste cooking oil collected in Europe is about 700,000–100,000 t/year [15].

Transesterification is the process by which the glycerides present in fats or oils react with an alcohol in the presence of a catalyst to form esters and glycerol [16,17].The conventional transesterification process has anyway, some drawbacks. First, it requires a lot of steps like the purification of the esters from the un-reacted reactants, separation of glycerol, which is the other product of the transesterification reaction, and catalyst recovery (Fig. 1). The free fatty acid (FFA) content of the vegetable oil should not exceed 2% when an alkaline catalyst is employed unless saponification reactions take place with a reduction in the catalyst activity. Also, the use of an acid catalyst has its own disadvantages because it is less efficient when compared to the alkaline one and the water produced by the FFA esterification with alcohol inhibits the transesterification of glycerides [18]. The acid-catalyzed process using waste cooking oil had less equipment pieces than the acid-catalyzed process for pretreatment of waste oils prior to alkali-catalyzed production of biodiesel, but the large methanol requirement resulted in more and larger transesterification reactors, as well as a larger methanol distillation column. Methanol distillation was carried out immediately following transesterification to reduce the load in downstream units in the acid-catalyzed process to produce biodiesel from waste oils but more pieces of equipment made from stainless steel material were necessary than in the alkali-catalyzed process to produce biodiesel from virgin oils and the acid-catalyzed process for pretreatment of waste oils prior to alkali-catalyzed production of biodiesel [19].

Another important drawback is connected to glycerol overproduction, which is a consequence of the increased biodiesel production achieved in the recent years. This has caused the price of glycerol to fall significantly while its cost of purification from alcohol, water and catalyst remains high [20].

It is important to evaluate the net energy balance of biomass as well as the biofuel that can be produced. Some researchers have estimated the net energy balance for biofuels derived from, corn ethanol [21–23], sugar cane ethanol [24], cassava ethanol [25,26], and soybean biodiesel [27], by calculating the net energy value (NEV) or net energy ratio (NER).

The conventional biodiesel production which involves the use of chemical catalyst is carried out at relatively high temperatures closer to the boiling point of the alcohol [28]. Energy is a fundamental ingredient in the process of economic development, as it provides essential services that maintain economic activity and the quality of human life. Thus, shortages of energy are a serious constraint on the development of low income countries. Shortages are caused or aggravated by widespread technical inefficiencies, capital constraints and a pattern of subsidies that undercut incentives for conservation [29].

Various studies and investigations have revealed that about 70–75%of the biodiesel fuel cost goes for the feedstock. The feedstock for biodiesel production differs from place to place and from country to country. In Iran, above 90% of edible oil is imported. Moreover, the cultivation of inedible plants has not been practiced so far. Therefore, a feasibility study was organized to find out the possible potential feedstock throughout the country [30]. The findings indicated that approximately 750 million liters (mL) of

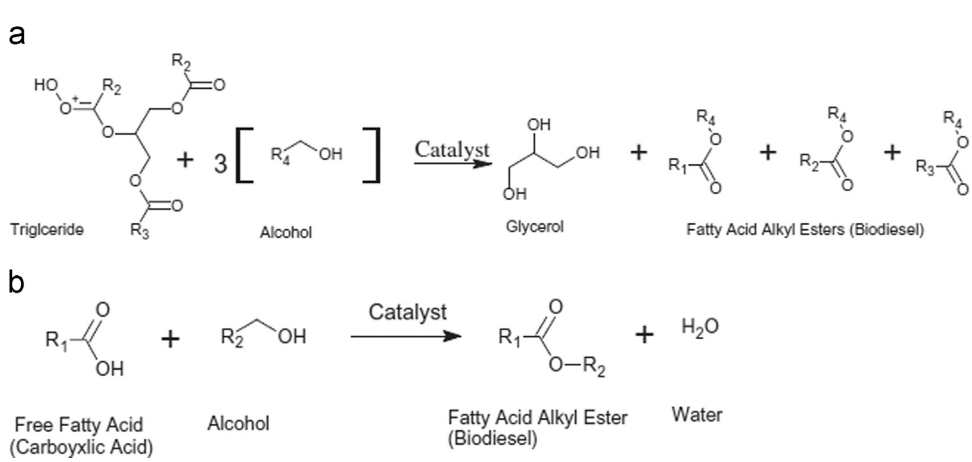

Fig. 1. Schematic representation of (a) transesterification and (b) esterification reactions.

biodiesel can be produced from waste vegetable cooking oils. This quantity is not fully collectable. The collectable quantity is about 50% (350 mL).

In the process of producing biodiesel, alcohol and catalyst are mixed to produce methoxide and then oil (Triglycerides) is added (Fig. 1). In this study, methanol, is used as alcohol, potassium hydroxide (KOH) and waste cooking oil are used as alcohol, catalyst and oil respectively.

The objective of this study is to perform the energy and economic analyses of biodiesel production from waste cooking oil (WCO) by the conventional transesterification method at Tarbiat Modares University in the Tehran province of Iran. This study is particularly important because there has not been any previous study focusing on energy and cost assessment of biodiesel production in Iran.

2. Materials and methods

This study is conducted at University of Tarbiat Modarres Biodiesel Lab, located in the Tehran province, Iran. Data is collected from a by biodiesel machine, performed by 3 replications in capacity of 2000 L during April–Jun 2012.

In this study in biodiesel production, energy inputs are waste cooking oil, alcohol (methanol), catalyst (KOH) (which are the basic materials for biodiesel production), human labor, electricity and machinery and the energy outputs include biodiesel, glycerol, additional alcohol, water, soap, monoglyceride, diglyceride. The economic inputs of this system contain expenses of human labor, waste cooking oil, alcohol, electricity, machinery and rant land. Biodiesel, glycerol and additional alcohol could be considered as economic outputs. The efficiency of the machinery for production of biodiesel in this study is 0.93% which is usually printed on the device including all production processes.

Based on the energy equivalents of the inputs and output (Table 1), the surveyed data including various energy and economic indicators are computed. Specifically, energy ratio (energy use efficiency), specific energy, energy productivity, net energy, fossil energy ratio (FER), energy intensiveness, energy intensity cost, energy intensiveness value and energy ratio cost are calculated. For the economic analysis, gross return, net return, benefit to cost ratio and productivity are also calculated.

For the growth and development, energy demands can be divided into direct (DE) and indirect energies (IDE) [39,40]. IDE included energy embodied in waste cooking oil, catalyst and machinery while DE covered human labor alcohol and electricity used in the biodiesel production. Non-renewable energy (NRE) includes alcohol, catalyst, electricity and machinery, and renewable energy (RE) consisted of human labor and waste cooking oil. The energy output includes the energy of WCO biodiesel and byproducts contain glycerol and additional alcohol.

Table 1
Energy equivalents of inputs and output in biodiesel production.

Particulars	Unit energy	equivalent (MJ unit^{-1})	Reference
A. Inputs			
1. Human labor	h	1.96	[30]
2. Waste cooking oil	Kg	25.00	[30]
3. Alcohol (methanol)	Kg	33.67	[31]
4. Catalyst (KOH)	Kg	19.87	[26]
5. Electricity	kWh	11.93	[30]
6. Machinery	Kg	8.00	[32]
B. Outputs			
1. Biodiesel	Kg	37.25	[33]
2. Glycerol	L	25.30	[34]
3. Alcohol (methanol)	L	33.67	[31]
4. Water	L	0.01	[35]
5. Soap	Kg	44.55	[36–38]
6. Monoglyceride	Kg	66.49	[36–38]
7. Diglyceride	Kg	67.26	[36–38]

Basic information on energy inputs and biodiesel expense is entered into Excel spreadsheets software (Version 2010). Expressions, such as the energy use efficiency, the energy productivity, the specific energy, the net energy gain, the energy intensiveness, energy intensity cost, energy intensiveness value, energy ratio cost, Energy intensity cost, Energy intensiveness value and Energy ratio cost were given by Mohammadshirazi et al. [29].

$$\text{Energy use efficeincy} = \frac{\text{Output energy (MJ L}^{-1}\text{)}}{\text{Input energy (MJ L}^{-1}\text{)}} \quad (1)$$

$$\text{Energy productivity} = \frac{\text{Yield (kg L}^{-1}\text{)}}{\text{Input energy (MJ L}^{-1}\text{)}} \quad (2)$$

$$\text{Net energy} = \text{Output energy (MJ L}^{-1}\text{)} - \text{Input energy (MJ L}^{-1}\text{)} \quad (3)$$

$$\text{Energy intensiveness} = \frac{\text{Input energy (MJ L}^{-1}\text{)}}{\text{Total production cost (\$ L}^{-1}\text{)}} \quad (4)$$

$$\text{Energy intensity cost} = \frac{\text{Total energy cost (\$ L}^{-1}\text{)}}{\text{Yield (kg L}^{-1}\text{)}} \quad (5)$$

$$\text{Energy intensiveness value} = \frac{\text{Total energy (MJ L}^{-1}\text{)}}{\text{Gross production value (\$ L}^{-1}\text{)}} \quad (6)$$

$$\text{Energy ratio cost} = \frac{\text{Total energy cost (\$ L}^{-1}\text{)}}{\text{Total production cost (\$ L}^{-1}\text{)}} \quad (7)$$

Fossil energy ratio (FER) was calculated by [27]:

$$\text{FER} = \frac{\text{Renewable fuel energy output (MJ L}^{-1}\text{)}}{\text{Fossil energy input (MJ L}^{-1}\text{)}} \quad (8)$$

It is worth noting that only fossil (nonrenewable) energy is included in the denominator. It does not include renewable sources of energy, such as solar and wind. Since the primary goal is to measure renewability, it makes sense not to include renewable sources in the denominator. FER does not measure system efficiency, as fossil fuel can be replaced by other renewable fuel.

Gross production value, gross return, net profit, net return, benefit to cost (BC) ratio and productivity were calculated by [29]

$$\text{Gross production value} = \text{Yield (kg L}^{-1}\text{)} \times \text{Price of commodity (\$ L}^{-1}\text{)} \quad (9)$$

$$\text{Gross return} = \text{Gross production value (\$ L}^{-1}\text{)} - \text{Variable production cost (\$ L}^{-1}\text{)} \quad (10)$$

$$\text{Net return} = \text{Gross production value (\$ L}^{-1}\text{)} - \text{Total production cost (\$ L}^{-1}\text{)} \quad (11)$$

$$\text{BC} = \frac{\text{Gross production value (\$ L}^{-1}\text{)}}{\text{Total production cost (\$ L}^{-1}\text{)}} \quad (12)$$

$$\text{Productivity} = \frac{\text{Yield (kg L}^{-1}\text{)}}{\text{Total production value (\$ L}^{-1}\text{)}} \quad (13)$$

3. Results and discussion

3.1. Analysis of input–output energy used in the biodiesel production

The energy inputs throughout the production of WCO biodiesel is shown in Table 2. To obtain total energy equivalent of biodiesel production, equivalent of input and output (Table 1) is multiplied to quantity per unit volume of biodiesel (L) (Table 2). The weight ratio of biodiesel to waste cooking oil is 0.99. Also the total energy input and energy output are calculated as 30.05 and 44.91 MJ L^{-1}, respectively, with the highest contribution of oil (77.08%), followed by methanol (19.44%), and machinery (1.73%) (Fig. 2). Due to the high amount of waste cooking oil and high equivalent (25 MJ/Kg), the waste cooking oil has the highest share of energy input. Additionally, according to the results, 0.036 h of human labor, 1.009 L of waste cooking oil, 0.219 L of alcohol, 0.015 kg of catalyst, 0.013 kWh of electricity and 0.009 h of machinery, are used for one liter of biodiesel production.

Table 2
Energy use pattern for biodiesel production.

Quantity (inputs and outputs)	Unit	Quantity per unit volume of biodiesel (L)	Total energy equivalent (MJ L^{-1})
A. Inputs			
1. Human labor	(h)	0.036	0.07
2. Waste cooking oil	(L)	1.009	23.16
3. Alcohol (methanol)	(L)	0.219	5.84
4. Catalyst (KOH)	(kg)	0.015	0.30
5. Electricity	(kWh)	0.013	0.15
6. Machinery	(h)	0.009	0.52
Total Energy input			30.05
B. Outputs			
1. Biodiesel	(L)	1.000	37.25
2. Glycerol	(L)	0.105	2.66
3. Alcohol (methanol)	(L)	0.110	3.69
4. Water	(L)	0.001	0.00
5. Soap	(L)	0.019	0.80
6. Monoglyceride	(L)	0.007	0.41
7. Diglyceride	(L)	0.002	0.10
Total energy output			44.91

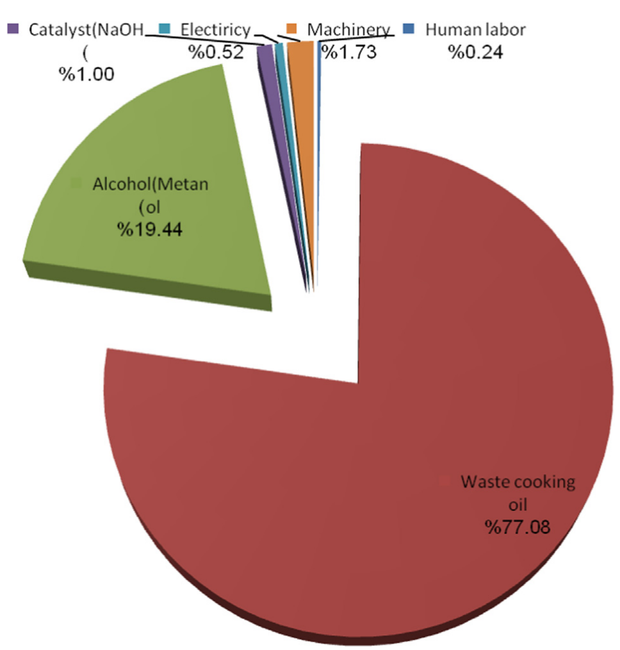

Fig. 2. Distribution of energy use from different inputs in biodiesel production.

Table 3
Energy input–output ratio in biodiesel production.

Items	Unit	Biodiesel
Energy input	MJ L^{-1}	30.0
Energy output	MJ L^{-1}	44.9
Energy use efficiency	–	1.49
Specific energy	MJ kg^{-1}	26.44
Energy productivity	kg MJ^{-1}	0.04
Net energy	MJ L^{-1}	14.9
Fossil energy ratio	–	1.3
Energy intensiveness	MJ $\$^{-1}$*	25.01
Energy intensity cost	\$ kg^{-1}	0.59
Energy intensiveness value	MJ $\$^{-1}$	12.02
Energy ratio cost	–	0.43

* Convert Rial to Dollar[41].

Table 4
Total energy input in the form of direct, indirect, renewable and non-renewable for biodiesel production (MJ ha^{-1}).

Form of energy (MJ L^{-1})	Biodiesel	(%)
Direct energy	6.07	20.38
Indirect energy	23.69	79.62
Renewable energy	23.23	77.31
Non-renewable energy	6.82	22.69

Table 5
Economic equivalents of inputs and output in biodiesel production.

Particulars	Unit energy	equivalent (\$ $unit^{-1}$)	Total cost and income equivalent (\$ L^{-1})
A. Inputs			
1. Human labor expense	h	9.18	0.33
2. Waste cooking oil expense	L	0.65	0.66
3. Alcohol (methanol) expense	L	0.57	0.13
4. Catalyst (KOH) expense	Kg	3.26	0.05
5. Electricity expense	kWh	0.07	0.00
6. Machinery expense	h	3.18	0.03
7. Rant land expense	m^2	815.66	0.00
8. Service and maintenance expense	year	122.35	0.00
Total costs			1.20
B. Outputs			
1. Biodiesel	L	2.45	2.45
2. Glycerol	L	0.24	0.03
3. Alcohol (methanol)	L	0.24	0.03
Total incomes			2.50

Energy indices including energy ratio, energy productivity, specific energy, net energy, Fossil energy ratio, energy intensiveness, energy intensity cost, energy intensiveness cost and energy ratio cost of biodiesel production are presented in Table 3.

Energy output–input ratio is one of the important indicators to maintain efficiency in biodiesel production. The energy output–input ratio is calculated as 1.49 in biodiesel production, which means that for each MJ of energy consumed to produce biodiesel, 1.49 MJ of energy was obtained. NER (energy input/energy output) is 0.67 and Passell et al. [42] has come up with 0.64 using algae for biodiesel production. Also in this study, Biodiesel yield (g biodiesel/g oil) is 0.99 and Spinelli et al. [43] calculation is 0.99 using

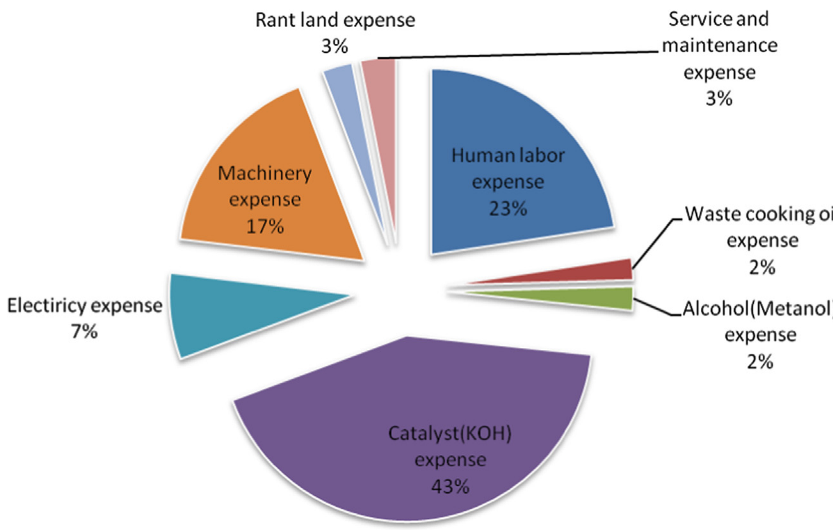

Fig. 3. Distribution of expenses use from different cost input in biodiesel production.

Table 6
Economic analysis of biodiesel production.

Cost and return components	Unit	Value
Gross production value	$ L^{-1}	2.499
Variable production cost	$ L^{-1}	1.197
Fixed production cost	$ L^{-1}	0.004
Total production cost	$ L^{-1}	1.201
Total production cost	$ kg^{-1}	1.057
Gross return	$ L^{-1}	1.302
Net return	$ L^{-1}	1.298
Benefit to cost ratio	–	2.081
Productivity	kg $$^{-1}$	0.946

sunflower. The average energy productivity of biodiesel is 0.04 kg MJ^{-1} which means that 0.04 unit output is obtained per unit energy consumption. The specific energy, net energy and energy intensiveness of biodiesel production are 26.44 MJ kg^{-1}, 14.9 MJ ha^{-1} and 5.78 MJ $$^{-1}$, respectively. Since the net energy is positive, it is concluded that in biodiesel production, energy is saved. It is also recommended for production due to positive net energy. Total energy cost is calculated by converting energy input to the other commodities such as barrel of oil and dollar in indices of energy intensity cost and energy ratio cost for production of biodiesel. The fossil energy ratio is 1.3. This means that 1.3 MJ L^{-1} renewable fuel energy output is obtained per 1 MJ L^{-1} fossil energy input. The estimated FER of biodiesel is 5.54, which is about 73% higher than the original FER reported by [27] using 1990 data, and 21% higher than that of reported by [44] which used 2002 data. Energy intensity cost, energy intensiveness value and energy ratio cost of biodiesel production are 0.59 $ kg^{-1}, 12.02 MJ $$^{-1}$ and 0.43, respectively.

The energy input classification used for biodiesel production as direct, indirect, renewable and non-renewable energy groups are presented in Table 4. As is shown in Table 4, the direct and indirect energy forms consist of 20.38% and 79.62% of total energy input, respectively. The contributions of renewable and non-renewable energies are 77.31% and 22.69% of the total energy input.

3.2. *Economic analysis of biodiesel production*

Input costs for biodiesel production are presented in Table 5 and Fig. 3. Total cost and total income are 1.2 and 2.5 $ L^{-1} for biodiesel production, respectively. The highest share of cost is waste cooking oil with 54.81%, and the second highest cost is for human labor with 27.75%.

Economic analysis of biodiesel production is shown in Table 6. According to the results of the research, the total expenditure for biodiesel production was 1.201 $ L^{-1} while the gross production value was found to be 2.499 $ L^{-1}. About 99% of the total expenditure is variable costs, whereas 1% is fixed expenditures. Based on these results, the gross return, net return, benefit to cost ratio, productivity from biodiesel production are calculated as 1.302 $ L^{-1}, 1.298 $ L^{-1}, 2.081 and 0.946 kg $$^{-1}$, respectively.

4. Conclusions

Based on the present study following conclusions are drawn:

1. The total energy input and energy output are calculated as 30.05 and 44.91 MJ L^{-1}, respectively. Waste cooking oil has the highest share of total energy input. For reducing the energy input and having greater efficiency, using algae is suggested.
2. Direct and indirect energy forms consist of 20.38% and 79.62% of total energy input, respectively. The shares of renewable and non-renewable energies are 77.31% and 22.69% of the total energy input. It is recommended to use biomethanol instead of methanol in order to increase the share of renewable energy from total energy input.
3. Energy ratio, specific energy, energy productivity, net energy, fossil energy ratio and energy intensiveness energy of biodiesel production are1.49, 26.44 MJ kg^{-1},0.04 kg MJ^{-1}, 14.9 MJ L^{-1}, 1.3 and 25.01 MJ $$^{-1}$, respectively.
4. The total cost and total income are 1.2 and 2.5 $ L^{-1}, respectively. The highest share of cost input is waste cooking oil with 54.81% of total cost followed by labor (27.75%).
5. According to the results of this research, the total expenditure for the production was 1.201 $ L^{-1} while the gross production value is found to be 2.499 $ L^{-1}. The benefit of the cost ratio is 2.081 according to the result of economic analysis of biodiesel production. The net return and productivity from biodiesel production are obtained as 1.298 $ L^{-1} and 0.946 kg $$^{-1}$, respectively. More benefit can be resulted by applying ultrasonic and microwave instead of the conventional method. So

the contact surface between oil and alcohol will increase per time unit.

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